

Introduction to
Fiber Optic Principles

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1. Introduction to Fiber Optic Principles

1.1 Basic Principles / Overview

Fiber optic transmission systems are used in a wide variety of applications from long haul high speed backbones employed by telephone companies to local area network applications and FDDI (Fiber Distributed Data Interface). Fiber optic systems have several advantages over traditional copper based systems:

- Much greater bandwidth (several orders of magnitude are theoretically possible).
- Immunity from electrical disturbances, ground loops, crosstalk, etc. In addition, no EMI radiation is generated.
- Much lighter. A 3 inch bundle of 900 twisted copper pairs can carry about 21,000 channels of traffic and weighs about 25,000 pounds / mile. A 1/2 inch fiber link with 12 fiber strands can carry about 300,000 channels and weighs about 200 pounds / mile. In addition, less duct space is required to route the cable within buildings.
- Better in 'hostile' environments, not affected as much by temperature, water, etc.
- Lower transmission loss. Typical loss on a fiber link is 0.2 dB / km. (On a copper based facility, loss is at least 5 dB / km.) For longer links, less repeaters are required.
- Better security as it is not possible to simply bridge onto the facility and monitor the traffic.

The principal disadvantages of fiber verses copper are:

- Higher equipment / installation costs in lower bandwidth applications.
- More complicated access / connection issues. Adding another segment / connection is more complicated, costly and time-consuming.
- Requires much more skilled personnel to maintain.

With the growth of high bandwidth applications and technologies, such as high definition television, multimedia, and ATM (Asynchronous Transfer Mode), it is clear that fiber based facilities will become increasingly predominant over the next 20 years.

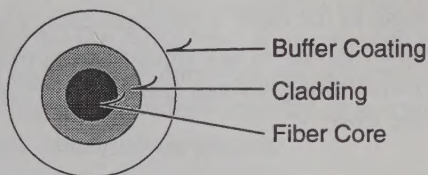
Fiber optic transmission systems utilize specialized light sources to send very high speed pulses down a fiber optic cable. The light sources send a 'non-diffused' beam of light at a particular wavelength. There are essentially two different types of sources currently in use:

- LED - Light Emitting Diode, lower cost / low dynamic range.
- LASER - More expensive, but provides better dynamic range.

Which type of light source used depends on the application. LED sources are used extensively in Multimode applications, while LASER sources are preferred in Single Mode applications. (See description in next section). A relatively low energy stream of light pulses is typically transmitted in the 830 - 1550 nm infrared range. (This is a slightly higher wavelength than visible red light at 620 nm.) The speed at which the light travels is affected by the physical medium used for transmission. Light travels fastest in a vacuum, and all other materials are rated relative to the speed in vacuum. The rate of the velocity of light in a vacuum to its velocity in a medium is called the medium's refractive index. For example, the refractive index of pure optical quality glass is about 1.471.

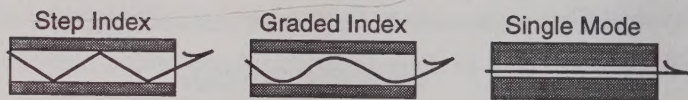
The typical fiber optic cable has essentially three different elements:

Typical Fiber Optic Cable



The core of the fiber transmits the actual signal. It is typically made of silica 'doped' with impurities, which increases the refractive index relative to pure silica. The cladding surrounds the fiber core and creates an optical interface which is designed to reflect almost all light back into the fiber. It is typically made from pure silica. The outer buffer coating is a plastic cover which provides physical protection for the fiber. Typically, there are a number of individual fibers enclosed in one fiber "bundle."

The first type of fiber optic cable put to use was called step index. In this design, the cladding has a different index of refraction from the core. The light bounces off the sides and is reflected back into the fiber core. The problem with this design is that the reflected light must travel a slightly longer distance than light which travels directly down the center of the fiber, thus limiting the maximum transmission rate. This design was improved with the use of graded index fiber. In this design, the index of refraction decreases in proportion to the distance away from the center of the fiber core. The light moves more quickly in the outer portion, thus compensating for the additional distance. The change in index also has the effect of 'bending' the light back towards the core. This change increased the transmission capacity by about a factor of 50. In the newest 'Single mode' design, the diameter of the fiber core is made so small that all the light travels in a straight line. Even the fastest fiber optic transmission facility in use today uses less than 5% of the maximum theoretical capacity of a Single Mode fiber.

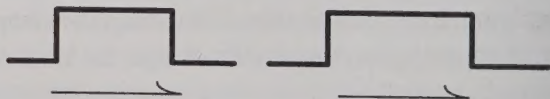


Over the length of the fiber, some light energy is absorbed due to impurities and is given off as a small amount of heat. Backscatter caused by reflections prevents some of the light from reaching the end of the fiber.

1.2 Singlemode verses Multimode

There are essentially 2 different types of fiber optic transmission schemes in use. Multimode fiber optic systems are typically used in 'short haul' applications such as LAN's and FDDI. Some multimode fiber is also in use in older CATV calling plants and some carrier networks. Recent growth in Multimode installations has been driven by LAN / FDDI applications. The term Multimode means that the diameter of the fiber optic core is large enough to propagate more than one mode (electromagnetic wave). Because of the multiple modes, the pulse that is transmitted down the fiber tends to become 'stretched' over distance. This is referred to as modal dispersion, and has the effect of reducing available bandwidth.

Modal Dispersion of a Light Pulse



The wavelenths used for the vast majority of Multimode applications are 850 nm and 1300 nm. There are other wavelenths used (e.g., 650 nm for plastic fiber, 820 / 870 nm in specialized applications). Most Multimode cable in use today is graded index in type, with a cladding diameter of 125 micron and fiber core diameter of 62.5 micron (typically referred to as 62.5/125 fiber).

Singlemode systems are generally used in long haul applications (10's or 100's of miles) and local loop applications in both the Carrier and CATV markets. Some large utilities, such as electrical power companies, also utilize single mode fiber optic backbones. As the name implies, single mode fiber is designed to propagate only one mode of light. It is therefore not affected by modal dispersion and has higher bandwidth capacity. It is considered to be the higher quality transmission system.

Wavelengths used in Singlemode applications are 1300 nm and 1550 nm. The majority of today's installed systems use 1300 nm wavelength technology. 1550 nm applications utilize newer technology and are designed for higher speed (OC12 + higher) applications. These systems are more sensitive to back reflections from connectors and sharp cable bends. They often require additional tests, such as optical Return Loss, to be run. Most Singlemode cable in use today is step index, with a cladding diameter of 125 micron and fiber core diameter of 8 micron (typically referred to as 8/125 fiber).

1.3 Fiber Optic Network Elements

In any fiber optic link, there are usually a number of standard elements that are used so that the facility provides good transmission quality. Additionally, standard design principals are typically used so that the facility can be easily maintained and tested. Since the installation of a fiber optic link represents a considerable capital outlay, care must be taken so that the investment is protected. In carrier / CATV applications this is even more critical as the cable must often be laid in 'harsh' external environments. Also note that fiber optic links typically carry a very large amount of traffic, so any extended outage can be very expensive for service providers who derive revenues from the traffic on the link.

Aside from the fiber optic cable and transmission equipment, most fiber optic links will contain most of the following elements:

- Splice(s), mechanical or fusion, used to join two pieces of fiber together
- Splice panel(s) to enclose any splices inside a premise
- Patch panel(s) to allow for test access / crossing over connectors
- Distribution panel(s) - combination splice / patch panel
- Storage panel(s) to hold some 'slack' cable
- Splice closures(s) to protect splices in exterior environments such as manholes (person-holes for the politically correct).
- Connectors and/or pigtail cables

1.4 Splices

Splices are used to join two pieces of fiber together. On a typical fiber optic link there are usually a number of splice points as it is typically not possible (or practical) to simply 'pull' one long continuous fiber. Splice quality is absolutely critical, because each junction point on the link introduces some degree of optical power loss or attenuation. Splicing joins the two fibers together both optically and physically.

Splicing requires a high degree of operator training and skill. Extreme care must be taken to ensure that the fiber is spliced together in a clean 'dirt free' environment. Even a small amount of contamination can lead to poor splice quality. The ends of the fibers must be flat and smooth with no cracks, chips, gouges or other physical defects. Specialized crimping / cleaving tools must be used to ensure accuracy. The cleaving tool is used to score / scribe the glass, which is then broken off to obtain as good a surface profile as possible. Cleaving is perhaps the most important part of the splicing process. If the ends of the fibers are not uniform, the splice results will be poor. A field microscope is often used to inspect the quality of the surface. Once the fiber has been properly stripped and cleaved, special alcohol pads are used to clean the surface in preparation for the final splicing.

Aside from the cleaving process, other factors can influence splice quality such as

- Core mismatch - the core diameter of the two fibers are different
- Lateral Core offset - the core is not centered within the fiber
- Angular misalignment - the two ends of the fibers must be less than 2 degrees apart
- Excess end separation - the two fiber ends are positioned too far apart
- Any contamination by dirt / dust
- Poor end polishing

There are essentially two different splicing techniques that are currently in use, fusion and mechanical splicing. Fusion splicing involves the fusing of the two fiber ends together using high temperature, which is typically achieved through use of high voltage electrodes. The two ends of the fiber must be aligned very precisely before they are fused together. Most fusion splicing equipment either does this automatically or provides controls to make very small adjustments. The actual fusing of the ends only takes a few seconds. After the fiber ends have been fused together, a splice protector is attached to protect the splice and provide strain relief.

Fusion splicing is the most effective splicing technique, and when done properly should result in less than 0.5 dB of loss across the splice. Even greater accuracy can be obtained, if very expensive 'lab type' fusion equipment is used. Fusion splicing equipment is typically very expensive and not very portable. In field environments this type of equipment is typically used inside a truck. Fusion splicers typically cost in the range of \$20K to \$50K.

Mechanical splicing is not quite as accurate as fusion splicing, as the two ends are not physically 'fused' together. In this technique, the protective splice cover is used during the splicing process. Some kind of curing agent, typically UV (Ultraviolet) fluid or some kind of heat sensitive fluid, is injected into the splice cover.

The fluid is then ‘cured’ inside the splice cover thus locking the two fiber ends in place. Mechanical splices can also be used to make temporary repairs if index matching fluid is used instead of a curing compound. This is particularly useful for quick repairs of broken cables. Numerous splicing kits are available that contain the cover and curing compound etc., to simplify the process.

Mechanical splicing does not require very expensive fusing splicing equipment. It is a low cost alternative in field applications. Each mechanical splice connector kit typically costs in the range of \$15 to \$20. Typical losses across the splice are less than 1 dB.

1.5 Splice / Patch Panels & Closures

Splice Panels are used to house one or more splices inside a protective cover. The panel typically has enough room to store several extra windings of cable. This facilitates the repair of bad splices as there is some ‘slack’ cable available. Splice panels are not designed for hostile outside environments.

Patch Panels provide test access to cross connection points for the fibers contained within one large fiber bundle of cable. A 0.5 inch fiber bundle for example might contain 20 fibers. In most installations, at least a couple of the fibers would not be used to transmit data. These ‘dark fibers’ are typically available as spares, in case any one of the other fibers should fail. Additionally, they are also often used for test purposes. (The assumption being that if the fiber bundle is damaged or cut, that the same problem will probably show up on all of the fibers.)

Patch panels have connection points for each fiber that is part of the bundle and patch cords (pigtail cables) to connect to the appropriate fiber in the other segment. Additionally, there are special test points which are often used for test purposes. In the event of a failure, traffic can be re-routed from one fiber to another simply by changing the connection. For very critical links, some kind of test equipment may be permanently attached to one of

the unused fibers. Patch panels can shorten the time taken to restore service to a couple of minutes rather than a few hours.

Distribution panels are essentially hybrids of splice and patch panels.

Storage panels are used to provide convenient and protected storage for 'extra / slack' cable. The purpose is to ensure that there is plenty of extra cable available for moving connections to another patch panel, test connections, etc. Without this slack, the process of making any changes would be very expensive and time consuming.

Splice closures are designed for hostile field environments where temperature, weather and environmental extremes are a problem. Inside the closure are splice organizer trays and room to store slack cable. Once all of the splices have been completed, they are 'hermetically' sealed inside the enclosures to ensure that no dirt or moisture can get inside. The closures provide strain relief for the cable and allow for the thermal expansion of the fibers. The closures are air tight and are often pressurized.

1.6 Connector Types and Pigtail Cables

There are many types of fiber optic connectors in use. Some are used only in Multimode or LAN applications while others are used in multiple applications. Most organizations that have fiber optic facilities typically try to standardize on one kind of connector if possible. This helps reduce cost, and avoid problems associated with having the wrong kind of connector / cable available. Unfortunately there is often a great deal of dissimilarity between different networks. No one connector accounts for more than 1/3 of all installations. In addition, there are significant differences between countries in terms of connector preference.

Typical Fiber Optic Connector (ST)



The most critical part of the connector is the ferrule, which is used to 'guide' the fiber optic core and maintain proper alignment. It is typically machined to a very high degree of accuracy. Typical connector losses should be less than 1 dB. From a physical connection point of view, there are essentially two different groups of connectors: threaded and bayonet style. The principal advantages of the bayonet connector are that it is not possible to 'over tighten' the connector and it is usually easier to connect. The main connector types are described below:

Connector Type	Uses / Description
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Threaded Connectors:

Biconic	Very common in telecommunication networks in the 1980's (Singlemode A applications).
Diamond	Very precise ferrule, used extensively in lab applications.
D4	Older connector type, provides good quality at a low cost, used in Telecom applications.
FC	Similar to the 2.5 micron Bayonet connector except for the coupling nut.
SMA	Used in FDDI applications.

Bayonet Connectors:

SC	SC-Type connector
ST	One of the most common connectors. Used in Multimode and Singlemode applications. A push / pull (rather than twist locking) version is also available.

Mini BNC

Predecessor of ST type connector, used in IBM Token Ring applications.

C) PC

Physical contact connector, often used in broadcast video applications. Angled versions also available. Supports both threaded and bayonet connectors.

Most patch cables or 'pigtailed' are typically purchased in standard lengths from fiber optic cable manufacturers in order to ensure good quality and reduce cost. The smaller the number of splices and connectors that must be done in field the lower the costs and probability of error.

1.7 dB verses Watts

Optical power levels can be measured using decibels or Watts. In field applications decibels are typically used, while Watts are more common in lab type applications. Decibels (dB) is a relative logarithmic scale measurement. However, when the dB scale is referenced to one milliWatt of optical power, the reading is expressed as "dBm." The actual formula used to calculate the value is: $\text{dBm} = 10 \times \text{Log}_{10}(\text{PowerIn}/\text{Ref Power})$. The relational scale is shown on the next page:

0 dBm	=	1 milliWatt
-10 dBm	=	0.1 milliWatt
-20 dBm	=	0.01 milliWatt
-30 dBm	=	0.001 milliWatt
-40 dBm	=	0.0001 milliWatt
-50 dBm	=	0.00001 milliWatt

Note: In some laboratory type applications, 0 dB is referenced to 1 microWatt.

1.8 Speeds of Transmission (e.g., OC12 or 622 Mbps)

Fiber optic systems are used to transmit information at set speeds or bit rates. The speed is often expressed in short hand (OCxx or Optical Carrier level xx) rather than bits per second. Following are the key 'standard' rates:

OC1	=	51.6 Mbps
OC3	=	155 Mbps
OC12	=	622 Mbps
OC24	=	1.2 Gbps
OC48	=	2.4 Gbps
OC96	=	4.8 Gbps

Newer technologies such as SONET, ATM (running over a SONET backbone) and Broadband ISDN are targeted to run over the higher speed ranges.

The majority of telecommunication transmission schemes in use today are based on Time Division Multiplexing. In the 'North American Copper world' for example, a DS1/T1 facility (1.544 Mbps) carries 24 64 Kbps channels plus framing overhead. A DS3/T3 facility (44.736 Mbps) carries 28 DS1 channels plus framing overhead.

Most public networks use some kind of hybrid system with copper based digital loop carrier systems to the customer premise, and fiber optic backbones to link the large switching nodes and distribution points. Typically the highest speed running over copper is DS3. To facilitate the interconnection between the copper and fiber worlds, methodologies for 'mapping or cross-connecting' DS1 or DS3 signals into OCxx facilities have been defined.

2. Fiber Optic Testing Overview

2.1 Types of Test Equipment Used / Test Practices

Numerous standards have been written by the IEC, TIA/EIA and ISO associations that cover most common test applications. These standards cover the measurement of cable and connector loss, absolute optical power levels and the impact of environmental factors such as temperature.

There are several different types of equipment that can be used to measure / test the optical performance of connectors, components and fiber optic links:

- Power Meters / Loss Test sets including separate or built in light sources.
- Optical Time Division Reflectometers (OTDR's).
- Fault finders (essentially low end OTDR's that do not provide graphic displays).
- Optical Return Loss testers.
- Visible / Red light sources & fiber identifiers.
- Talk Sets.
- Variable Attenuators.
- Inspection Microscopes.
- Bit Error Rate testers (BERT).
- Spectrum Analyzers.

Each of the above categories are not mutually exclusive. For example an OTDR might be equipped with an Optical Return Loss Option.

The most common pieces of equipment used when characterizing fiber optic links in a field type environment are power meters and OTDR's. Most carriers or telephone companies typically use both types of equipment when turning up new facilities or

when trying to sectionalize problems. Fiber optic power meters tend to be quite a bit less expensive than OTDR's and are typically much easier to use. Inspection microscopes are quite common in splice applications. Many third party contractors who specialize in 'pulling' cable use only low end power meters to verify continuity and power levels. The carriers then perform much more exhaustive tests to fully characterize the link, before the service is 'turned-up' and any traffic is put onto it.

Whenever tests are performed on a fiber optic link, the results are typically archived for future reference in case of problems. This is particularly true when the circuit is first installed. By keeping this reference information, it is possible to compare the performance of the facility against the original benchmark each time any change is made or problems are reported. Proper documentation of the exact location of splice points, etc., can be critical later when attempting to resolve problems. In many organizations, the physical volume of data that must be archived can be a major problem.

In laboratory environments, precision is typically the most important requirement. In addition, many pieces of equipment such as spectrum analyzers are used which are rarely seen in the field. In manufacturing facilities, highly sophisticated / automated systems are often used to ensure proper quality control. The equipment used is often much more accurate than that used in the field. Most rolls of fiber optic cable that are shipped for example, will come with copies of the actual Q.A. test results.

2.2 Power Meters

The term power meter applies to a generic group of test products that are capable of measuring a received optical power level in Watts or dB. A solid-state detector (Silicon or Germanium) is typically used. The power meter is often combined with a light source, in which case it is some times referred to as 'Loss Test set.' In general, the more generic power meter term is used.

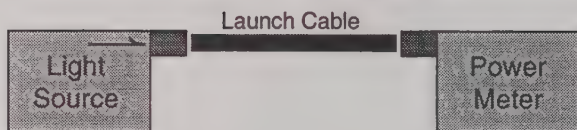
All tests performed with power meters are made unidirectionally; i.e., a light source (of known strength) is connected at one end of the fiber optic link, and an optical power level detector is connected at the other end of the link. The overall end to end loss across the facility is then measured. The tests are then usually repeated in the opposite direction. Bi-directional results are usually important, as the attenuation is often different in each direction.

Many of the 'low end' power meters have separate light sources. The principal advantage of having the source separate from the power meter is in reducing equipment cost. Provided that the fiber optic link is short it is possible to 'get by' with just one power meter and light source (i.e. attach the light source at one end, measure the output at the other end, and then reverse the procedure). For longer links, two power meters and two light sources are typically required to avoid excessive travel time for the technicians.

The typical steps required in performing a loss test with most power meters are as follows (see diagram):

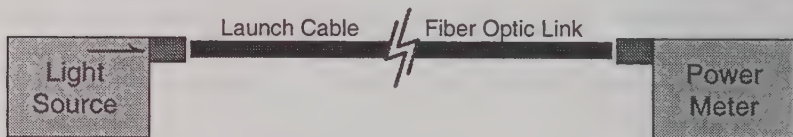
1. The light source is connected directly to the power meter with the 'launch' cable.
2. The power reference level (in dBm) is measured and recorded. On some power meters, it is possible to then set or 'zero' this reference value.
3. The fiber optic link is then inserted between the launch cable and the power meter.
4. The overall loss across the link and launch cable is measured in one direction.
5. The link loss in one direction is then calculated by subtracting the reference value from the overall value measured in step 4.
6. Steps 4. and 5. are then repeated in the opposite direction.
7. The average loss or 'loss budget' (in both directions) is then calculated by averaging the results of steps 5. and 6.

Setting the Reference Value



$$\text{Net Loss} = (\text{Loss across the link}) - (\text{Reference value})$$

Measuring Loss Across the Link



With the above procedure the user must either 'reference' the power meter or perform some arithmetic subtractions to determine the net loss across a link. To test the fiber in both directions, the user must make at least two connections on each end of the fiber. This introduces the possibility of some error due to connector misalignment or a dirty connector.

When using a power meter, there are basically 2 different kinds of light sources that can be used: LED or Laser. LED sources are significantly less expensive, but provide a much lower level of optical power output. LED sources are used extensively in Multimode applications, while Laser sources are preferred in 'long haul' Singlemode applications. Many of the Laser sources are also 'temperature stabilized' to avoid inaccuracies induced through temperature variations.

Power meters are extremely useful in helping to quickly determine if there are any major overall optical power losses across a link. These tests do not however give any indication about the actual characteristics of individual fiber optic segments / splices along the section under test. OTDR's are used to provide this level of detail, which is very useful in sectionalizing problems.

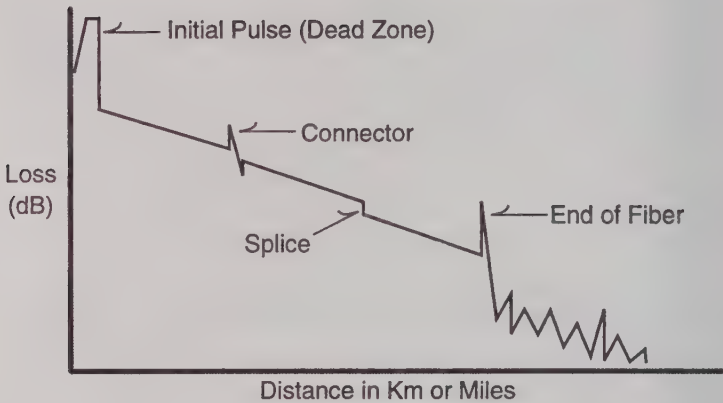
2.3 OTDR's / Fault Finders

Optical time domain reflectometers use the phenomenon of backscatter to determine the characteristics of a fiber link, find faults and optimize splices. An OTDR functions by sending out a short, high powered pulse of light into the link under test. Very sensitive detectors are used to measure the amount of light backscattered toward the test set. All elements (cables, connectors, couplers, splices, etc.) of the fiber optic link reflect some light back toward the test set. The pulse is attenuated as it travels away from the source while the reflected light is attenuated on the return toward the source. The measured signal returned is thus affected by the actual loss as well as the backscatter coefficient and index of refraction of the fiber under test. If one assumes that these parameters remain essentially constant, then splices, connectors and breaks (which introduce 'discontinuities') can be measured and characterized. Also note that if the wrong parameter values are used when the calculations are made, the results will be inaccurate.

OTDR's also have the advantage of requiring only one direction to be tested to determine fault locations. Particularly on long links this can be very helpful in terms of reducing the amount of time required to sectionalize a problem.

OTDR's typically present the measurement results in a graphical format with loss shown on the vertical axis and distance shown on the horizontal axis. There is usually some sort of capability to 'zoom in' on the events of interest. They allow the user to determine the average loss across a section of the fiber (dBm/km) or around some event of interest, such as a splice.

Typical OTDR Display



The above example illustrates a few points of interest. While the high energy level pulse is being sent out, it is not possible for the receiver to accurately measure the backscatter, as it is 'saturated' with too much energy. The reason for this is that the transmitter and receiver are both connected to the same fiber using an optical coupler. This area is called the 'Deadzone' and is typically 1 - 150 feet (50 meters). Splices typically show up as small dips in the curve as the fiber ends are joined together without any air gap in between. Typical losses are less than 0.1 dB. Variations in the backscatter coefficient between the two pieces of fiber can, in some cases, make the splice appear to amplify rather than attenuate the signal. Connectors typically show a larger amount of loss as some of the light will 'bounce off' the end of the connector at the air gap. This loss is called 'fresnel loss' and can represent up to 4% of the optical power being transmitted.

OTDR's are significantly more expensive than power meters, and are used for a different purpose. Both PC card based and standalone versions are available. The determination of the location of splices, connectors and discontinuities is often 'automated' by the OTDR.

Fault finders, which do not have large graphic displays, use this technique to indicate the approximate distance to (in meters or feet) to splices or faults. The instrument's indicated location of splices or cable faults is only of help if there is some way to correlate the reading to the physical cable length. This type of information is typically recorded when the cable is first installed.

2.4 Optical Return Loss Testers

One other test area that is growing in prominence is 'optical return loss' or connector 'backscatter.' This is a measure of how much light is reflected back where two pieces of fiber are joined. Backscatter is a very important issue in high bit rate 1550 nm applications. Even though the majority of Single Mode facilities are running at 1300 nm, many carriers are anticipating long term migration towards 1550 nm networks and want to ensure that their facilities are capable of handling this wavelength. Optical return loss is a test capability that can often be found on both power meters and OTDR's. Customer preference and price will dictate which type of instrument will be equipped with this functionality.

2.5 Visible / Red Light Sources & Fiber Identifiers

Visible red light sources send light pulses in the range of 650 nm. They are used in two basic applications:

- To identify specific fibers in a bundle. The source is connected at one end of the link, and the fiber end appears red at the far end making it readily identifiable.
- To locate breaks or other faults on an exposed section of fiber. If there are any breaks in the cable, the cable jacket will glow red at the fault point.

Fiber identifiers are used to passively determine which fibers are active or 'dark' inside a fiber bundle; i.e., they do not require that the link be taken out of service. They work under the principal that if the fiber optic cable is bent, some amount of the light energy will escape through the fiber jacket. These devices typically require the fiber to be bent at a particular radius. Sensitive receivers are used to determine if there is any light energy escaping from the fiber.

2.6 Talk Sets

One of the problems that is frequently encountered when trying to install fiber in field environments is the lack of communication facilities to enable technicians at either end of a link to communicate. Copper telephone lines are not always co-located with fiber optic facilities. Cellular phones provide another alternative, but can be very expensive to use in long distance applications. In addition, cellular phones do not always work in remote areas or deep in the basements of large buildings.

Fiber optic talk sets provide a solution to the above problem as they make it possible for two users to have a voice conversation over one of the fibers within a fiber bundle, assuming that there is end to end continuity. Talk sets are very handy in both installation and maintenance activities. Another variation of this theme is to add a message exchange capability to the test sets that are used to test the link. Rather than having a voice conversation, the users exchange preprogrammed messages that can be selected from a menu. Message exchange capabilities, when integrated with other test functions such as power level measurement, provide a much lower cost alternative than talk sets.

2.7 Variable Attenuators

Variable attenuators are used to test the transmission range of optical equipment. They essentially simulate a long fiber optic link and add a variable amount of attenuation. By using a source, which transmits at a known optical level, and by varying the attenuation, it is possible to determine how sensitive the receiving device is. For example if a receiver is rated as accurate to -50 dBm and the optical source outputs light at -10 dBm, then it should be possible to attenuate the signal by 40 dBm before the receiver is no longer able to accurately recover the light energy.

2.8 Bit Error Rate Testers

Bit error rate testers (BERTs) are used to test the ability of a link to carry traffic. The BERT transmits a known test or bit pattern down the link at a particular speed. At the receiving end, the pattern is recovered and then compared to the test pattern. If there are no bit errors in the observed pattern then the link is said to be 'error free.' If the facility is degraded, or some of the network elements are not functioning correctly, then bit errors will be counted. The number of bit errors verses the number of bits received is often expressed as a ratio called Bit Error Rate (BER).

BERTs for high speed ranges (e.g., 2 Gbps) are typically very expensive. On much lower speed copper based facilities, BERTs are much less expensive and more prevalent.

2.9 Spectrum Analyzers

Spectrum analyzers are used to test the optical performance of transmitters, receivers and other optical components. They can be used to measure power intensity verses wavelength of an optical source or the opto-electrical response characteristics of a receiver. These tools are typically quite expensive, and are not usually used in a field environment. They are most often used in manufacturing and product certification applications.

To ensure interoperability of different components in an optical network, each component must have operational characteristics that fall within a well defined 'footprint.' SONET and FDDI standards, for example, specify footprints for connectors, light sources, etc. For transmitters, such as lasers for example, the peak energy transmitted should be at the desired frequency with much less energy being transmitted at other frequencies. For receivers, such as photo diodes, the electrical output is measured in terms of linearity of voltage verses optical power received at a particular wavelength as well as the dynamic response. Spectrum analyzers may also be used in conjunction with BERTs in order to 'certify' optical systems.

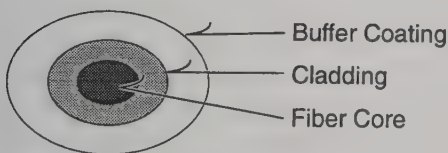
2.10 Sources of Error

There are many factors that can impact the ability of a fiber optic link to successfully carry traffic without error.

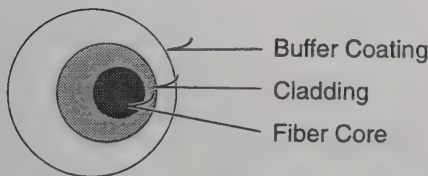
- Optical couplers: There is always some gap between ends of 2 fibers that are coupled together. This causes some loss in optical power as well as some back reflections. This is typically minimized through use of highly polished surfaces as well as non-reflective coatings. Index matching fluid is sometimes used to minimize the 'fresnel loss' between two fiber ends that are joined together.
- Alignment of optical couplers: Misalignment of the fiber core can greatly diminish optical power output.
- Connector cleanliness: Dirty surfaces can dramatically increase light absorption and light scattering. Microscopic dust particles, grease, etc., can make an enormous difference in connector losses.
- Wavelength variation: Any drift in wavelength can have an enormous influence as most receivers are accurate only within a very narrow wavelength band.

- **Splice accuracy:** Precision splicing (mechanical or fusion) requires a fair degree of accuracy, skill and repeatability. Flaws, even those which are only visible using a microscope, can have a big impact on the fiber optic facility. Typical fusion splice losses should be in the range of 0.05 to 0.1 dB. Small dust particles, misalignment of the 2 fiber ends, etc., can cause significant problems with backscatter and excessive attenuation. Proper alignment of the two fiber ends is critical in ensuring good splice quality.
- **Cable characteristics and quality :** Generally speaking, the fiber optic cable itself is not the largest source of unexpected light loss. Most manufacturers of fiber optic cable use very tight tolerances, and extensively test the fiber before shipment to the customer. Often they must guarantee 'free of charge' replacement of any defective cable so they do everything possible to avoid problems. The key areas of importance for fiber optic cable are the uniformity of the cable diameter, how round the fiber / cladding are, and how well centered the fiber is with the cladding.

Oval Shaped Fiber Optic Cable



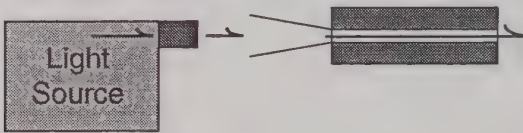
Off Center Fiber Optic Cable



Problems are more often related to poor splices, alignment of couplers, etc., rather than cable faults.

- **Launch Quality:** It is very important that the optical source be properly aligned with the cable, and that the distance from the launch point and the cable be properly selected to ensure that the maximum amount of optical power is transferred to the cable. The “numerical aperture” refers to the angle at which the light must enter the fiber in order to avoid being reflected. This angle is typically less than two degrees.

Numerical Aperature



- **Macro Bends:** Sharp bends (i.e., a radius of 2 inches or less) in the cable give rise to attenuation problems. Care must be taken to ensure that the fiber optic cable is not excessively bent. Problems can also be caused by tie wraps being excessively tightened.
- **Noise Floor:** All detectors introduce some level of noise in the measured signal. Depending on how low the signal is (e.g., -65 dB) the actual ‘noise floor’ may begin to approach that of the ‘detector noise.’ When this occurs, the accuracy of the measurement becomes suspect.
- **Operator Error:** There are essentially two areas where operator error can be a problem. The first is related to how the equipment is connected to the circuit under test, cleanliness of the connectors, etc. The second area arises from procedural errors such as incorrectly setting reference points, the index of refraction, arithmetic errors, etc. Computational errors are typically more of a potential problem with ‘low end’ power meters while incorrect parameter setting is common with OTDR’s.

Over a typical Single mode facility, in general one does not expect to see more than 30 dB of loss over a 50 mile fiber segment. The

number of splices, how accurate they are, etc., obviously has a big impact.

2.11 Calibration

Calibration of fiber optic test equipment is an important issue. All fiber optic test equipment requires periodic calibration to ensure test accuracy. Generally speaking this is typically recommended every 12 - 18 months or so, as the measurements will tend to 'drift' slightly over time. Calibration should not be confused with 'zeroing' a reference reading at the beginning of a test, which is a very common requirement when using low end power meters.

To calibrate any test instrument a 'known' reference standard must be used. Industry accepted norms dictate that the reference device must be 'traceable' to the US National Institute of Standards Testing (NIST) or to the IEC (outside North America). In laymen's terms this means that the equipment used in the calibration procedure (typically an expensive highly accurate source or receiver) must have been 'calibrated and certified' by NIST.

3. SUMMARY AND REFERENCES

We hope this introduction to fiber optic transmission and testing proves helpful in gaining an understanding of this media. There are a number of excellent reference books on the market today which go into more detail on all the subjects covered in this handbook and more. If you are involved with the installation and testing of fiber optic links or planning one in the future, Wavetek highly recommends selecting and studying more detailed information concerning the subject.

With regard to LAN installations, many new testing standards are currently in draft form. The following is a partial list of industry standards that currently address or will address fiber optic link testing and their status at the time of this writing. If a specific standard is not yet approved, published and readily available, the fiber optic link designer should provide the testing requirements and limits for each link to be tested.

North America

ANSI/TIA/EIA 526-14, OFSTP, Rev. 1990-11-00

ANSI/TIA/EIA 568A (draft form as SP2840A Annex H)

International

ISO/IEC 11801 (draft form)

IEEE 802.3, FOIRL

Europe

EN 50173 (draft form)

EN 50174 (draft form)

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